Spectral responses of GaAs photodiodes fabiricated by rapid thermal diffusion

著者	Usami Akira, Kitagawa Akio, Wada Takao, Suzuki Masakuni, Tokuda Yutaka, Kan Hirofumi
journal or publication title	IEEE Election Device Letters
volume	13
number	1
page range	59-60
year	1992-01-01
URL	http://hdl.handle.net/2297/24543

doi: 10.1109/55.144951

Spectral Responses of GaAs Photodiodes Fabricated by Rapid Thermal Diffusion

Akira Usami, Akio Kitagawa, Takao Wada, Masakuni Suzuki, Yutaka Tokuda, and Hirofumi Kan

Abstract—**The spectral responses of GaAs photodiodes fabricated by rapid thermal diffusion (RTD) of Zn are presented. We tried controlling the p$^+$-n junction depth by the heating rate of RTD, without extending the diffusion time. It is found that Zn diffuses from the surface to a deeper position as the heating rate increases. Consequently, the spectral response of photodiodes formed by RTD is strongly dependent on the heating rate of RTD. A large improvement in the short-wavelength response between 400 and 800 nm is observed as the heating rate decreases.**

ZN DIFFUSION into GaAs is an important technique for fabrication of optoelectronic devices and integrated circuits [1]. The conventional furnace process requires high temperature and long diffusion time. Consequently it is difficult to prevent surface degradation and to form shallow heavily doped p-type layers. Rapid thermal diffusion (RTD) with tungsten-halogen lamps has an inherent advantage of short time processing [2] and is appropriate for the GaAs device processing, for instance, because it is expected that a redistribution of prior doped impurity and surface decomposition are suppressed [3]. RTD has been applied for the fabrication of a shallow p$^+$-n junction in GaAsP, and this shallow junction is suitable for the construction of light-emitting diodes and photodiodes [4]. Furthermore, the RTD of Zn into GaAs from a doped SiO_2 film has potential applications in the Zn-diffused junction stripe and the current blocking layer for laser diodes, and shallow p$^+$-n junctions for the photodiodes on monolithic optoelectronic integrated circuits. In this letter, we present the results of RTD from Zn-doped oxide films on n-type GaAs substrates, and the spectral response of the p$^+$-n junction photodiodes fabricated by RTD of Zn.

The wafers used in this study were (100) Si-doped LEC n-type GaAs ($n \simeq 3 \times 10^{17}$ cm^{-3}). Zn-doped oxide films with a thickness of 200 nm were formed on the wafer surfaces by spinning a solution consisting of alcohol, tetrahydroxysilane, and carboxyester. Then these were placed face up on a Si wafer susceptor in flowing N_2 gas in a quartz tube and irradiated by a cylindrical array of tungsten halogen lamps. The temperature during RTD was controlled by a PID system with a fine thermocouple attached on the Si wafer susceptor. It was feared that the thermal response of the GaAs sample was different from that of the Si susceptor, so the temperature of a dummy GaAs sample is also measured by another very fine thermocouple (100 μm in diameter). The RTD temperatures given in this letter indicate the temperatures of the dummy samples. RTD of Zn was carried out at temperatures from 910 to 1070°C for hold times of 0 and 9 s at diffusion temperatures with heating rates of 10, 31, 53, and 83°C/s, and the sample was cooled without any control. The initial rate of cooling was about −30°C/s. After Zn diffusion, samples were etched in HF to remove the oxide films. To investigate the diffusion of Zn into GaAs by RTD, the carrier profiles were estimated by an electrochemical *CV* method. For the fabrication of photodiodes, Al and Au–Ge were evaporated onto the p$^+$ layers and substrates for ohmic contacts, respectively. The junction area of p$^+$-n photodiodes is 1.67 mm^2.

The p$^+$-n junction depth from the GaAs surface is shown in Fig. 1 as a function of the diffusion temperature, where the hold time at the diffusion temperature was 9 s. The junction depth was determined by a crosspoint of the bulk carrier concentration and the hole concentration of the Zn-diffused layer, which were measured by the electrochemical *CV* method. Zn concentration at the surface of the RTD sample at 910°C (2×10^{18} cm^{-3}) is much lower than other samples (over 2×10^{19} cm^{-3}).

Fig. 2 shows the profiles of Zn acceptor concentration obtained after RTD for 9-s hold time with heating rates of 10, 53, and 83°C/s. Zn diffuses from the surface to a deeper position as the heating rate increases in spite of the shorter processing time. The diffusion temperature of the sample in RTD depended on the heating rate, when a parameter for the diffusion temperature given in the PID controller was fixed. The peak temperatures of the GaAs dummy samples are 930°C (10°C/s), 960°C (53°C/s), and 971°C (83°C/s). This result indicates that the heating rate dependence of Zn diffusion is not mainly due to the temperature fluctuation caused by slow thermal response of GaAs sample. A possible candidate for the origin of heating rate dependence of RTD is the RTD-induced thermal stress at the SiO_2/GaAs interface in the heating stage. The RTD-induced stress is estimated at 1.2×10^6 dyn/cm^2, assuming that a temperature difference of 100°C occurs between GaAs and SiO_2. This thermal stress intensity is below the dislocation yield of GaAs. How-

Manuscript received August 14, 1991; revised November 3, 1991.
A. Usami and T. Wada are with the Department of Electrical and Computer Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466, Japan.
A. Kitagawa and M. Suzuki are with the Department of Electrical and Computer Engineering, Faculty of Technology, Kanazawa University, 2-40-20, Kodatsuno, Kanazawa 920, Japan.
Y. Tokuda is with the Department of Electronics, Aichi Institute of Technology, Yakusa, Toyota 470-03, Japan.
H. Kan is with Hamamatsu Photonics K. K., 1126-1, Ichino-cho, Hamamatsu 435, Japan.
IEEE Log Number 9105491.

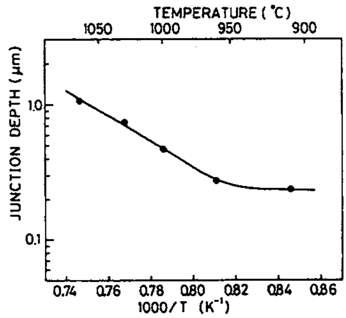

Fig. 1. The diffusion temperature dependence of the junction depth in RTD GaAs for 9-s hold time with a heating rate of 53°C/s.

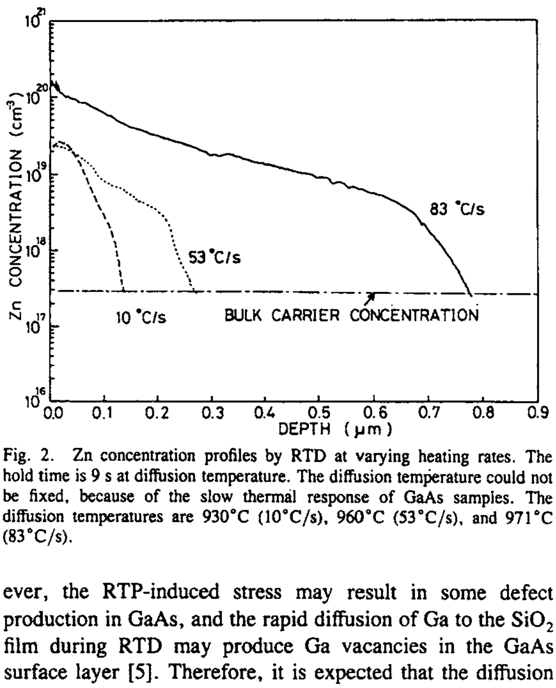

Fig. 2. Zn concentration profiles by RTD at varying heating rates. The hold time is 9 s at diffusion temperature. The diffusion temperature could not be fixed, because of the slow thermal response of GaAs samples. The diffusion temperatures are 930°C (10°C/s), 960°C (53°C/s), and 971°C (83°C/s).

ever, the RTP-induced stress may result in some defect production in GaAs, and the rapid diffusion of Ga to the SiO_2 film during RTD may produce Ga vacancies in the GaAs surface layer [5]. Therefore, it is expected that the diffusion coefficient of Zn depends on the heating rate and cooling rate in RTD.

The p^+-n junction depth is controlled without extending the short diffusion time of RTD and without elevating the diffusion temperature considerably, since it can be increased by increasing the heating rate. Fig. 3 shows spectral responses as a function of the heating rate of RTD for 9 s. The diffusion temperatures during RTD are mentioned above. The spectral response slightly increases over the wavelength of 800–1000 nm as the heating rate increases. On the other hand, large improvements in shorter wavelength response are observed as the heating rates are decreased. The short- and long-wavelength responses for the shallow junction are to be attributed mainly to contributions from the p-type surface side and

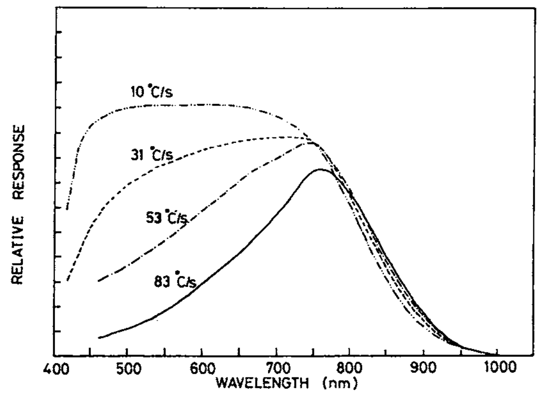

Fig. 3. Spectral responses of RTD photodiodes as a function of the heating rate. The hold time is 9 s at diffusion temperatures.

n-type bulk side, respectively. Therefore, if the junction depth from the surface is decreased equally to a reciprocal absorption coefficient at short wavelength, the short-wavelength response for the shallow junction diode is improved by an increased contribution from the n-side.

In summary, the spectral responses of GaAs p^+-n photodiodes fabricated by RTD of Zn into Si-doped GaAs from Zn-doped SiO_2 films were presented. The spectral responses of these photodiodes are dependent on the heating rate of RTD. In particular, a large improvement in the short-wavelength response between 400 and 800 nm is observed as the heating rate decreases. GaAs photodiodes will be most sensitive if fabricated with a heavy surface concentration of Zn and a low n-type bulk concentration, that is, a steep diffusion profile easily obtained by RTD is appropriate for the photodiodes.

Acknowledgment

The authors would like to thank T. Murakami of Hamamatsu Photonics K.K. for his help in preparing devices used in this study.

References

[1] H. Kawano and K. Mori, "Formation of p-n junction for efficient $GaAs_{1-x}P_x$ LEDs by diffusion from doped spin-on oxide," *Japan. J. Appl. Phys.*, vol. 15, p. 727, 1967.

[2] A. Usami *et al.*, "Shallow junction formation for silicon solar cells by light-induced diffusion of phosphorus from a spin-on source," in *Proc. 18th IEEE Photovoltaic Specialists Conf.*, 1985, pp. 797–803.

[3] P. Pearah *et al.*, "Rapid thermal annealing of modulation-doped $Al_xGa_{1-x}As$/GaAs heterostructures for device applications," *J. Appl. Phys.*, vol. 56, p. 1851, 1984.

[4] A. Usami *et al.*, "Diffusion of Zn into $GaAs_{0.6}P_{0.4}$:Te from Zn-doped oxide films by rapid thermal processing," *Mater. Res. Soc. Symp. Proc.*, vol. 92, p. 393, 1987.

[5] M. Katayama *et al.*, "X-ray photoelectron spectroscopic study of rapid thermal processing on SiO_2/GaAs," *Appl. Phys. Lett.*, vol. 54, p. 2559, 1989.